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INTERIM REPORT

SRDS Project No. 320-101-01N
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Intra-agency Agreement No. CE/RD56-64-5

EVALUATION OF AN ILS GLIDE SLOPE MONITOR TECHNIQUE USING A MONITOR DETECTOR WITH TWO ANTENNAS

DECEMBER 1965

FEDERAL AVIATION AGENCY
Central Region
Systems Maintenance Division
Kansas City, Missouri

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This report has been approved for general availability

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ABSTRACT

This report concerns the installation and evaluation of a newly developed clearance monitor system for the standard ILS null reference glide slope.

The new system was proposed by Mr. Henry H. Butts of the Federal Aviation Agency's Systems Research and Development Service. It is designed to provide an indication of the glide slope path width that is independent of snow cover conditions or changes in path angle.

With minor exceptions, the test monitor system performed in the manner predicted by Mr. Butts. These exceptions relate principally to the detector point location in the near field, but do not derogate the system's application.

This report finds that the proposed monitor system is superior to the present monitor system. It finds the principal disadvantages are the additional height required for the monitor antenna support and the cost of the additional components required.

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INTRODUCTION

The clearance detector of the normal null reference glide slope monitor is located at the maximum point of the second lobe of the sideband antenna radiation pattern. Through comparison of the levels of 90 cycle and 150 cycle voltages in the detector output, an approximate indication of the path width may be obtained. This condition remains true only as long as the path structure remains symmetrical about the nominal path angle.

A change in the elevation of the electrical ground plane, as may occur due to the accumulation of snow between the antenna and the detector, causes the apparent path angle to increase. Although the path width remains nearly constant, it is no longer equally disposed about the nominal path position and the clearance detector gives an erroneous indication of path widening.

Although this is not a hazardous condition, in extreme cases the path widening indication reached the alarm limit of the monitor and caused it to shut the equipment down, resulting in a needless loss of service.

In February, 1963 Mr. H. H. Butts of the Systems Research and Development Service proposed a clearance monitor system that would be less affected by changes in the electrical ground plane.

This monitor system was installed on a test basis at Kinross AFB, Sault Ste. Marie, Michigan from April 1963 to May, 1964. The report that follows concerns that test.

DEFINITIONS

Certain terms and symbols are used in this report as a convenience. When used, these terms and symbols will assume the definitions presented here.

Carrier Sidebands Audio. The recovered modulation component that was transmitted as a part of the carrier energy, from the carrier antenna. The symbol representing Carrier Sidebands Audio is Ecs.

Coefficient of Reflection. A measure of the ability of a plane to reflect energy that impinges on its surface. The measurement is a decimal value, less than 1, that is roughly related to the percent of reflection that results from an impinging signal.

Far Field. The area, forward of the glide slope facility toward the outer marker, in which proximity phase effect becomes negligible, usually beyond 3000 feet from the glide slope antennas.

Ground Plane. The physical surface of the earth at the base of the antenna. For this report the ground plane is considered to have a near unity reflection coefficient so that reflection of the radiated carrier and sideband energy will occur normally at the physical surface.

Near Field. The area between the antennas and the far field, in which proximity phase must be taken into consideration.

Proximity Phase. This is the phase difference that occurs in the near field between the energy radiated by the carrier antenna and the energy radiated by the sideband antenna. It is due to the sideband energy having to traverse a longer path than the carrier energy to reach the point of observation. The symbol for Proximity Phase is Bp.

Reflecting Plane. That plane, parallel to the earth's surface, from which reflection of the radiated carrier and sideband energy occurs. Normally this is the ground plane, but it may be above ground plane under snow cover conditions.

Space Sidebands Audio. The recovered modulation component that was transmitted, separately from the carrier energy through the sideband antenna. The symbol for Space Sidebands Audio is Ess.

Standard Monitor. This term, as well as the term "standard monitor detector", refers to the normal, null reference, monitor/detector system that is presently in use through the Federal Aviation Agency.

Test Monitor. This term, as well as the term "test monitor detector", refers to the two antenna monitor/detector system under evaluation and for which this report is written.

BACKGROUND

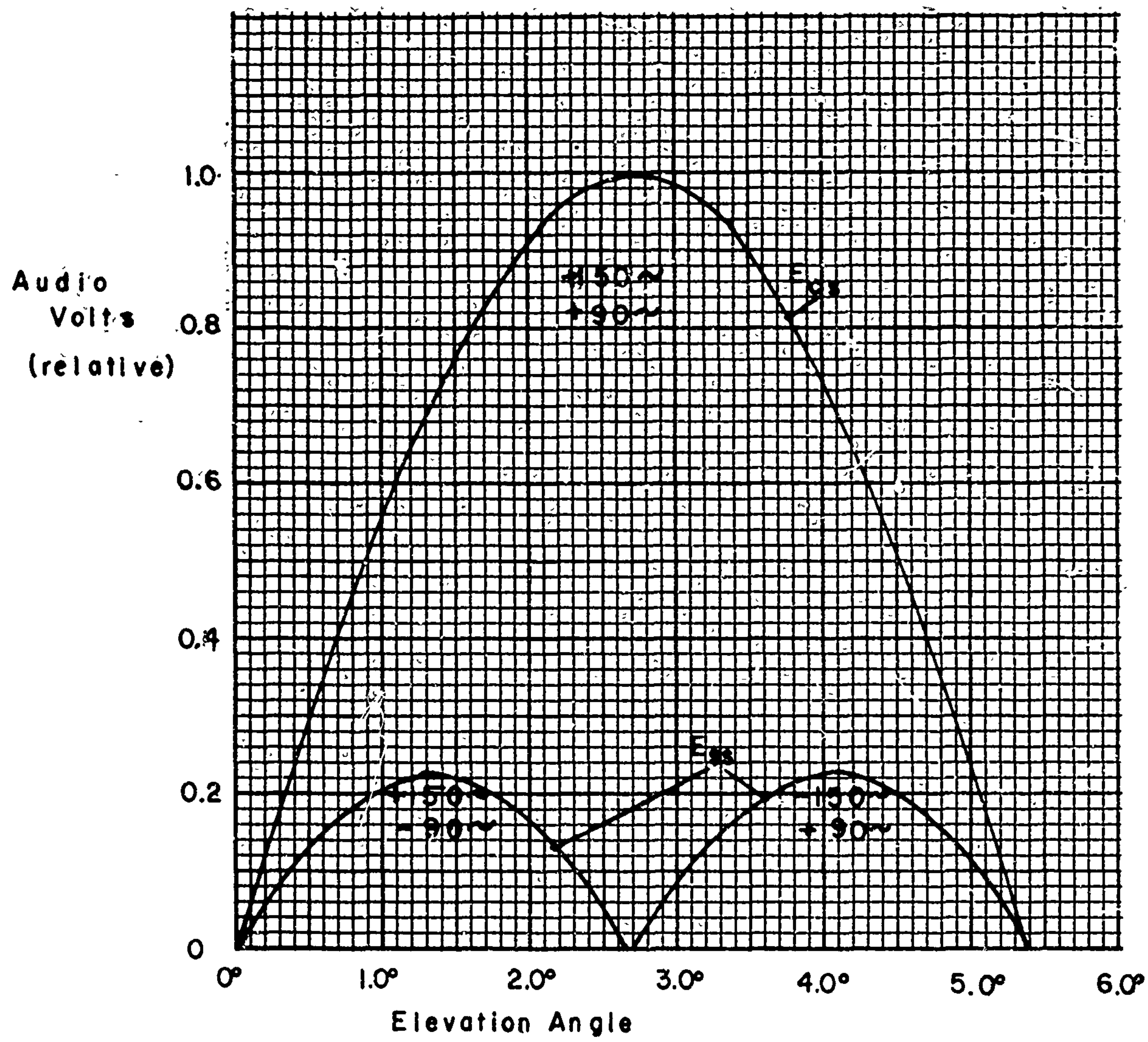
The lobe structure of the carrier and sideband antenna radiation is a function of the height of the glide slope antennas above the reflecting plane. In the null reference type glide slope, the path center is the first null of the sideband antenna radiation pattern. The heights of the carrier and sideband antennas are so proportioned that the carrier antenna radiation pattern will have a maximum value at the path center. Figure 1 is a plot of these radiation patterns.

The 90 cycle and 150 cycle components of the space sideband signal are phase locked 180° out of phase. The same components of the carrier signal are phase locked and in phase. As a result of this audio phase relationship of the 90 and 150 cycle sidebands, and the RF phase relationships established in the antenna system, the 150 cycle audio predominates below path and the 90 cycle audio predominates above path in the far field. In the path center the 90 and 150 cycle components are equal since the path center is in the null of the sideband radiation pattern. Within the near field area the signal that predominates, and the amount of space sideband energy recovered, is dependent on the proximity phase. Between the 90° Bp point and the 270° Bp point the 150 cycle signal will predominate above path and the maximum space sideband energy will be recovered at the 180° Bp point. Beyond the 90° Bp point, toward the middle marker, the 150 cycle signal will predominate again below path, as it will between the 270° Bp point and the 540° Bp point.

Figure 2 is a sketch of the manner in which proximity phase, Bp, affects the slope structure in the near field.

The clearance detector of the standard null reference glide slope is normally located at the 180° Bp point in the near field and is placed above path at the maximum point of the second lobe of the sideband radiation pattern. The principal purpose in placing it at the 180° Bp point is to provide monitoring of phase changes in the glide slope projector system. By placing it in the maximum of the sideband energy lobe a favorable level of 150 cycle signal preponderance over the 90 cycle signal is obtained. The location above path is favored because the signal that predominates there, 150 cycle, is the predominating signal in the critical below path area in the far field.

Under stable operating conditions, that is, when Bp and the reflecting plane are constant, the clearance detector is a reasonable means of evaluating the width of the glide path. This is true because the sideband radiation lobe structure is symmetrical about the path center. If the value of Bp changes from the nominal of 180° the clearance level will decrease giving a false indication of path widening. Fortunately, the Bp value remains fairly stable at most glide slope sites. Where it is not, it may be stabilized by the use of metal matting between the antennas and the 180° point to provide a constant coefficient of reflection.



(Relative audio voltages shown are for a 1.4° path width.)

FIGURE 1. RADIATION PATTERN OF TYPICAL 2.7° GLIDE SLOPE

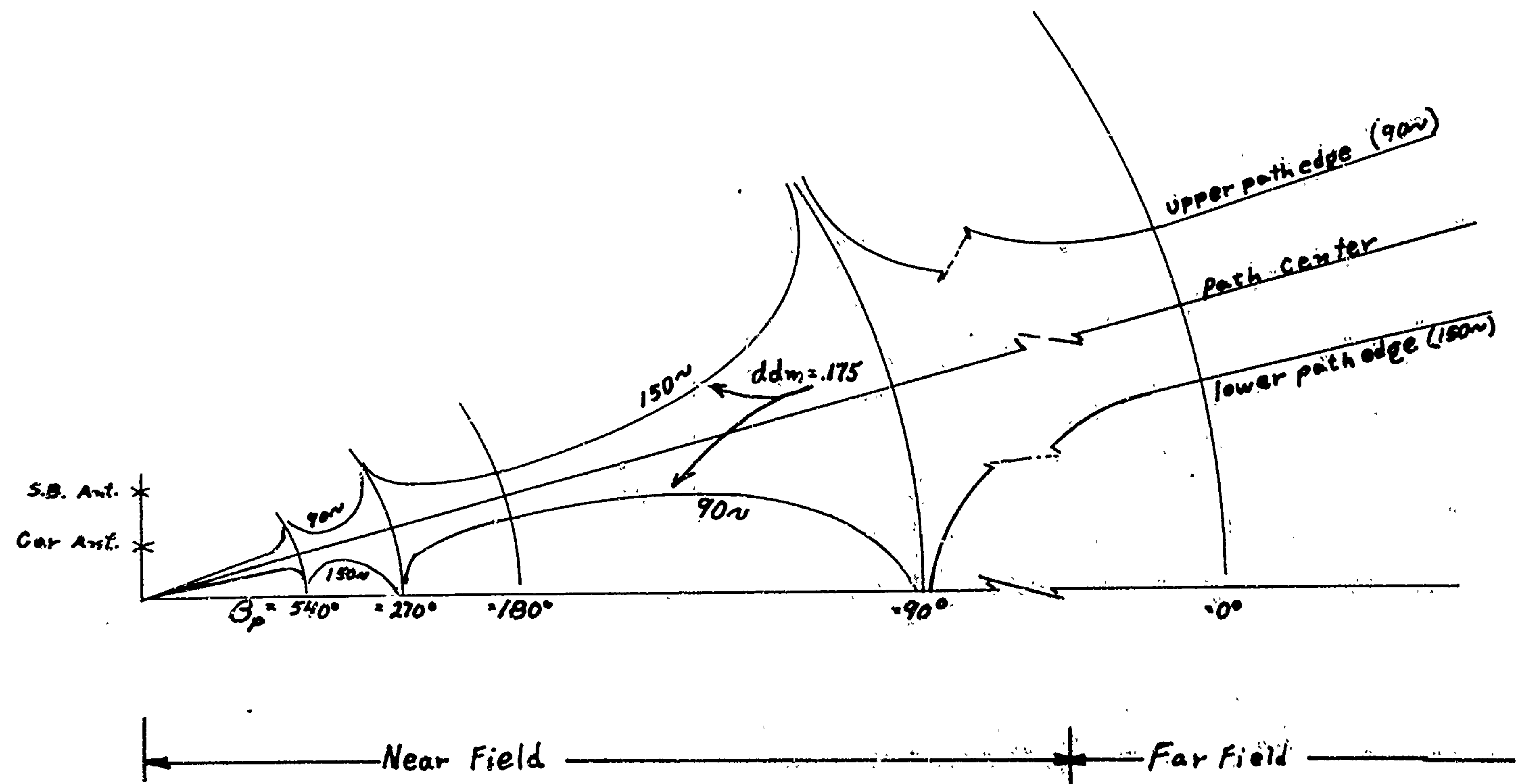


FIGURE 2. EFFECT OF PROXIMITY PHASE, B_p, ON PATH WIDTH

The stability of the reflecting plane is concerned with its longitudinal axis toward the detector point and its elevation relative to the ground plane. Truly significant deviations of the electrical plane rarely occur naturally except as the result of snow accumulation on the ground plane. When snow does accumulate, the reflecting plane will appear to rise an amount that is related to the depth of snow accumulation, but not necessarily equal to the accumulation. That is, a snow depth of two feet may raise the reflecting plane by four inches or twenty, depending on the snow's reflection coefficient. An additional fact that has been noted is that the amount of rise will vary from hour to hour through a period when the surface of the snow may be melting or freezing into a crust.

This rise in the reflecting plane causes a change in the lobe structure of the carrier sideband radiation patterns. The path center moves upward because the angle of the first null of the sideband radiation pattern has increased. The actual path width, in the far field, is virtually unchanged because normal accumulations of snow do not significantly disrupt the symmetry of the sideband radiation pattern about the increased path angle.

The standard monitor clearance detector, however, is located with respect to the nominal (or normal) path angle rather than the increased path angle. For this reason, as the lobe structures rise with the rising reflecting plane, the clearance detector receives a decreased sideband signal and produces a false indication of path widening or lowered below path clearance. The rising ground plane also produces a change in Bp that further reduces the recovered space sideband signal, Ess, and causes additional widening indications.

The occurrence of false path widening indications under snow accumulation conditions is a major factor in wintertime glide slope outages. It becomes more significant when it is realized that this condition is prevalent under weather conditions in which the glide slope is most likely to be required.

PROPOSED MONITOR SYSTEM.

Mr. H. H. Butts, RD-321, Systems Research and Development Service of the Federal Aviation Agency, proposed a monitor system to provide true path width monitoring capability and overcome the problem of sensitivity to snow accumulation. This proposal, contained in a memorandum to the files dated February 18, 1963, suggested the feasibility of using twin antenna inputs to the normal clearance detector. This system uses two antennas, one mounted above and one below the normal path center, connected through a bridge/phaser/power divider system to the detector input. It was reasoned that if a true path width change occurred, both antennas would receive a lower value of sideband energy and the detector output would reflect this condition. On the other hand, if the total path raised, the width remaining stable, the output of one antenna would increase and the output of the other would decrease. Under this condition the detector output would remain fairly constant.

Also contained in the proposal was the suggestion that the phaser in the detector antenna system would permit locating the twin antennas at any desired distance without regard to proximity phase. This would permit moving the pickup further out and improve the apparent ground coefficient of reflection through the decreased grazing angle of the radiated glide slope signals.

Figure 3 is a schematic diagram of the detector portion of the proposed monitor system. The remainder of the clearance channel of the monitor system is unchanged and performs as at present.

The proposed monitor system is not concerned with path angle evaluation and the path monitor remains as presently used.

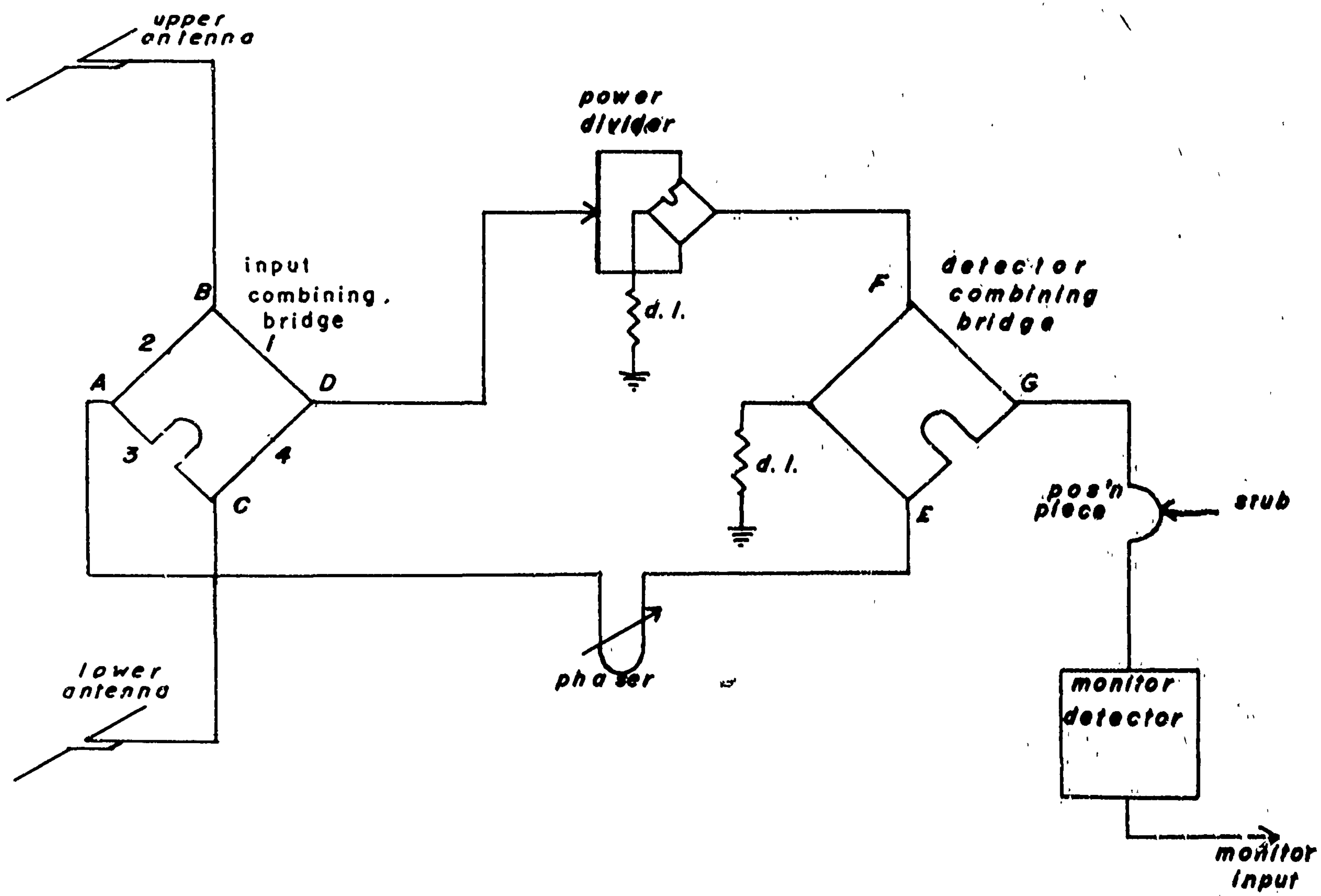


FIGURE 3. TEST MONITOR DETECTOR SCHEMATIC

THEORY OF OPERATION.

Refer to Figure 3 and to the Typical Glide Slope Radiation Pattern, Figure 1. Note that sideband signals, as well as carrier signals are picked up by both antennas. As outlined previously, the RF phase of sideband energy received by the lower antenna, in the first sideband lobe, will be opposite to that received by the upper antenna, located in the second sideband lobe.

The carrier energy received by the two antennas will not be of different phase because both antennas are in the same lobe of the carrier signal.

By design, the antennas are located so the received sideband energies are equal and the received carrier energies are equal. These equal signal levels are coupled to the combining bridge by equal lengths of coaxial cable.

In the combining bridge, the energy from each antenna is divided by the two legs. The carrier energy from each antenna travels the equal length legs, 1 and 4, of the bridge and appear at bridge corner D as the sum of the energies in the two branches of D. The carrier energy in the unequal legs, 2 and 3, cancel because of the phase reversal that occurs in the 180° section of leg 3 and will not appear at A. The space sideband energies of the two antennas, because of their phase relationship, will cancel at corner D. The 180° additional length in leg 3 will put the sideband signals in phase at point A. The signal at A is pure space sidebands and equal to the sum of the space sideband signal in legs 2 and 3.

The combining bridge has, in effect, combined the output of the two antennas but into separate sideband and carrier components.

The "carrier corner" output, D, is fed to a power divider and to a second bridge, the detector bridge, in the detector input circuit. The purpose of the power divider is to permit adjustment of the ratio of carrier and sideband audio voltages in the output of the detector.

The "sideband corner" output, A, is fed through a phaser to the detector bridge where it is combined with the carrier signal at the detector input. One-half of the carrier and sideband energy is lost in the dummy load of the detector bridge. The phaser in the sideband circuit permits the carrier and sideband energy phase to be adjusted to the optimum, zero or 180°, relationship.

The output of the detector bridge is fed to the detector through the stub and positioning piece combination that is used to match the detector input impedance to the dummy load, thus maintaining bridge balance.

OPERATIONAL LIMITATIONS.

Consideration of the theory of operation of the proposed system suggests that certain limits will apply. As stated before, the sideband levels from the two antennas must be equal, as must the carrier levels, in order to achieve cancellation in the combining bridge. Although Bp is equal for both antennas, a change in Bp will dephase the sideband/carrier relationship, thereby affecting the audio ratio in the detector output. This latter effect is offset to some degree by placing the detector further from the glide slope projector antennas. Figure 4 is a plot showing the change in Bp that occurs at different distances from the antennas for an increase of 18" in the reflecting plane level.

Consider now the operation under conditions of snow cover that has caused the glide angle to increase. The sideband levels from the two antennas are no longer equal. The carrier levels will also be unequal, to a lesser degree. Complete cancellation of carrier will not occur at point A and some carrier will be present at that point. Similarly, complete sideband cancellation will not occur at point D and some sideband energy will be present at the carrier corner, D. It becomes apparent that these added signals in the detector can cause significant errors in the audio output ratios.

The problem can be nearly overcome by locating the twin antennas at the 90° point of proximity phase. Thus the undesired carrier at the sideband corner of the combining bridge will be at quadrature with the sideband signal at point A, Figure 1. Also, the undesired sideband signals at point D will be at quadrature with the carrier at that point. We must now consider the results of passing these signals through the power divider and the phaser of the detector bridge. The undesired sideband signals will be reduced by the power divider, remaining at quadrature with the carrier signal also fed through this power divider. The undesired carrier signals from point A of the combining bridge pass through the phaser at quadrature with the sideband signals from point A. The fact that both undesired signals are at quadrature with the desired signals suggests that they will be in phase with each other when the desired signals are phased together at the detector bridge. The fact is, they may be in phase with each other or 180° out of phase, depending on which antenna feeds into the leg of the combining bridge that contains the extra 180° length. It will also depend on the phase chosen between the desired carrier and sideband signals at the detector bridge.

Note, for example, the schematic of Figure 3 shows the lower antenna feeds into the combining bridge leg that contains the extra 180° section. As the path angle rises with increasing electrical plane, the carrier signal from the upper antenna will increase as the lower antenna carrier signal decreases. The undesired carrier will have the same phase as the desired carrier. After phasing the desired signals together in zero phase, the undesired carrier and sideband signals will be in zero phase. If the desired signals are phased to a 180° relationship, the undesired signals will have the same 180° phase

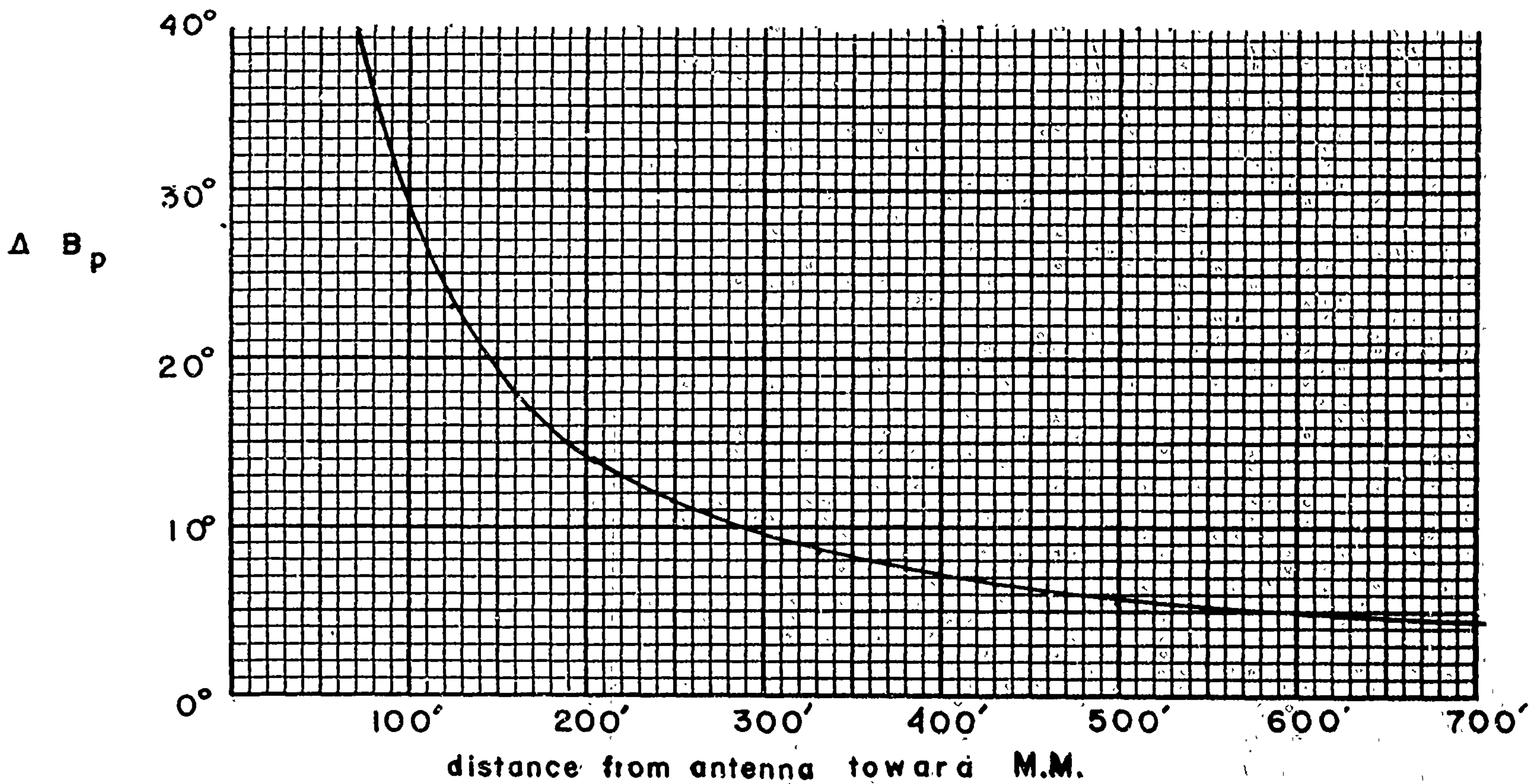


FIGURE 4. CHANGE IN PROXIMITY PHASE AS A RESULT OF AN 18" RISE OF THE REFLECTING PLANE NORMAL GLIDE ANGLE OF 2.7°

relationship to each other.

Consider the opposite connection of the antennas to the combining bridge; that is, with the added 180° length leg in the upper antenna's circuit. Now the undesired carrier at point A, which is still the "sideband corner" of the bridge, will be 180° out of phase with the desired carrier at the opposite corner. In this case, the undesired signals will have a phase relationship to each other that is the opposite of the phase relationship the desired signals have to each other. More simply put, if the desired signals are phased to produce a preponderance of 150 cycle audio from the detector, in the first example the undesired signal would also have 150 cycle predominating. In the second example, the reverse would be true. With the same phaser setting, the 90 cycle component of the desired signal would predominate while the predominating undesired audio frequency would be 150 cycle. These relationships are shown, using phasors in Figure 5.

Other factors will also affect the level and the influence of undesired signals from the combining bridge. The linearity of the changes of sideband and carrier signals in the two antennas, the amount of change the electrical plane undergoes, and the reduction factor that occurs in the power divider will each have an effect.

It may appear that these limitations on the detector location will limit the efficacy of the proposed system. Such is not the case. The undesired signals may actually be put to use to counteract the change in Bp that occurs due to the rising reflecting plane. This use is explained in some detail in appendix of this report.

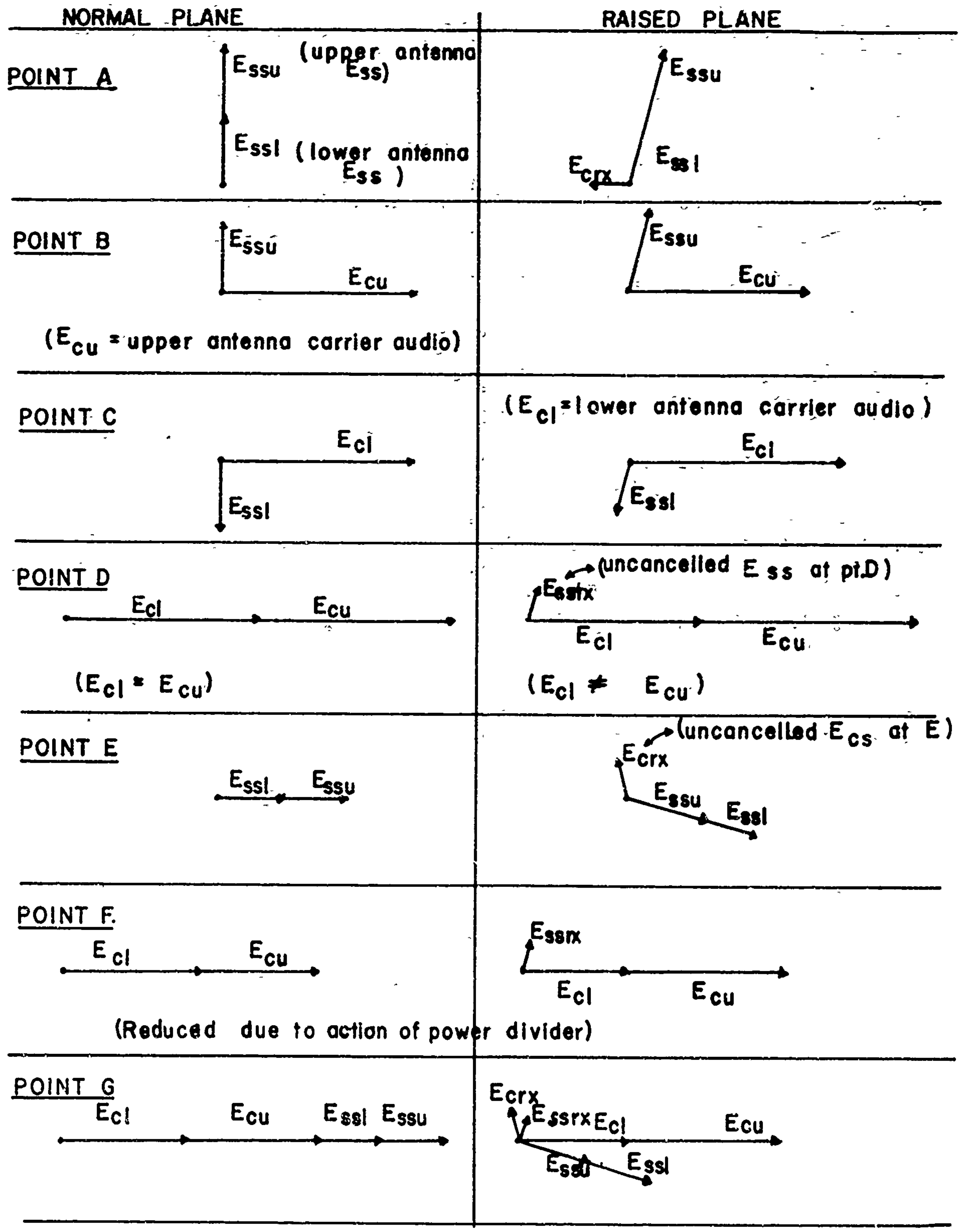


FIGURE 5. VECTOR RELATIONSHIPS BETWEEN THE AUDIO COMPONENTS OF THE CARRIER AND SPACE SIDEBAND RF SIGNALS AT DIFFERENT POINTS IN THE SCHEMATIC OF FIGURE 3 UNDER NORMAL AND RAISED PLANE CONDITIONS

THE TEST SITE.

The ILS glide slope on Kincheloe AFB, Sault Ste.Marie, Michigan was chosen as the test site to evaluate the proposed system. Kincheloe AFB is a base of the Strategic Air Command and, in deference to security regulations, no pictures of the site or test installation were made. Figure 6 is a sketch of the ILS glide slope area, copied from unrestricted drawings supplied by the U. S. Army Corp of Engineers and by other offices of the Federal Aviation Agency.

Several factors were considered in selecting the Sault Ste.Marie site. One of these is the considerable volume of snow encountered there. As indicated in the graph, Figure 7, showing the snowfall for the period of March 1, 1964 to April 15, 1964, snowfalls may be expected frequently in the spring and the total accumulations may be considerable. The winter of 1963/1964 was, incidentally, an unusually light snowfall winter as compared to the average for this area.

Another factor considered in selecting the test site was the availability of heavy duty snow removing equipment and the excellent cooperation provided by the Air Force in clearing snow from the glide slope area. It should be noted that the total accumulations shown in Figure 7 do not apply to the immediate glide path area.

The ILS at Kincheloe AFB serves Runway 15, which is 17,000 feet in length and 300 feet wide. The glide slope frequency is 335.0 mcs and the published glide angle is 2.68^{o} with nominal width of 1.4^{o} (0.7^{o} normal approach envelope).

The equipment used includes a Type TUS glide slope projector with a CA-1363 monitor. The test monitor installed was also a CA-1363.

The glide slope facility is 400 feet off centerline of Runway 15 (250 feet from the runway edge) and the site elevation is 795 feet AMSL. The soil is sandy and has a reflection coefficient of approximately .85 at the detectors. The facility has a history of dependable service and the quality of maintenance is excellent. Power is supplied by commerical sources with engine generator standby power.

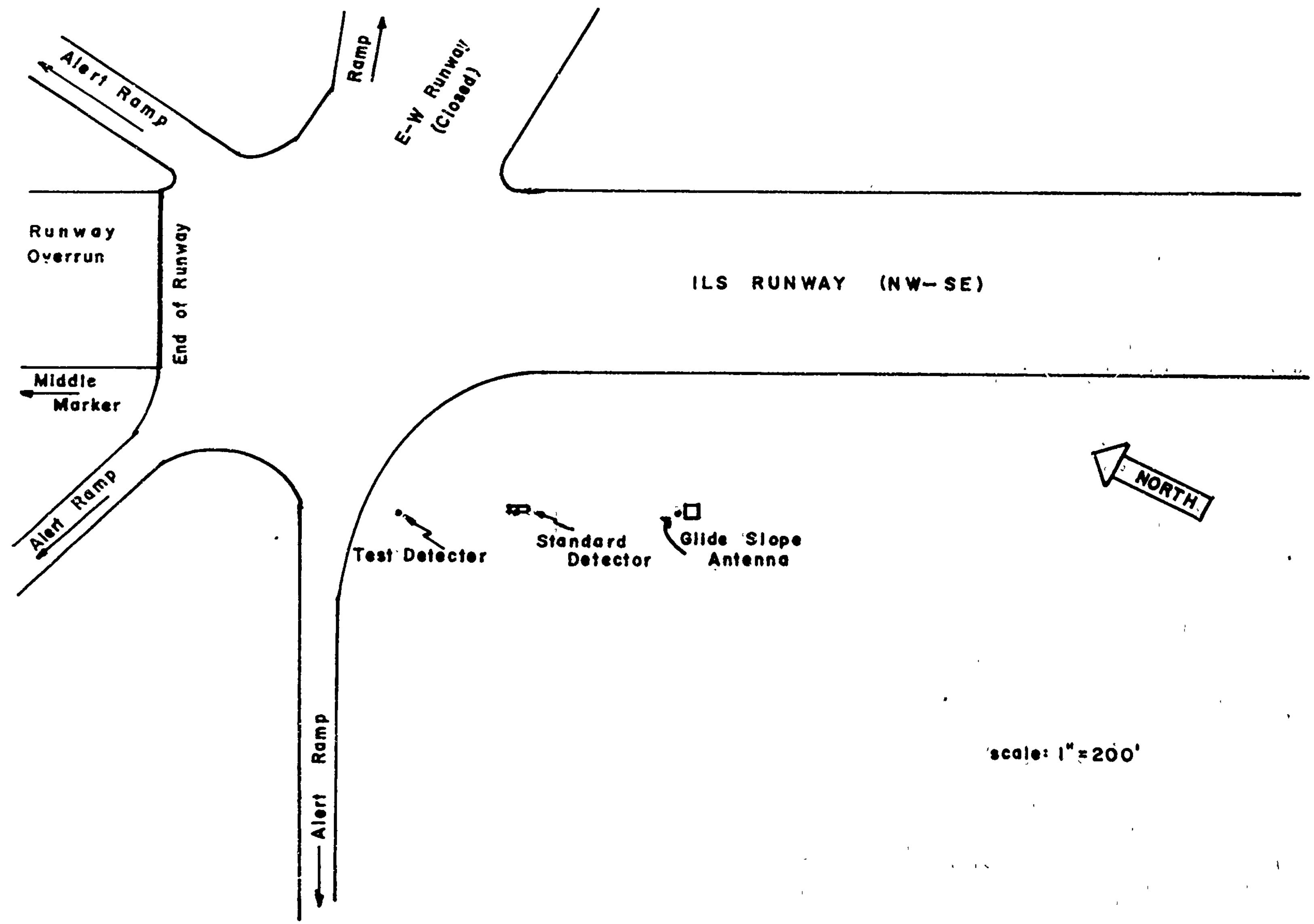


FIGURE 6. ILS GLIDE SLOPE LAYOUT, KINCHELOE AFB

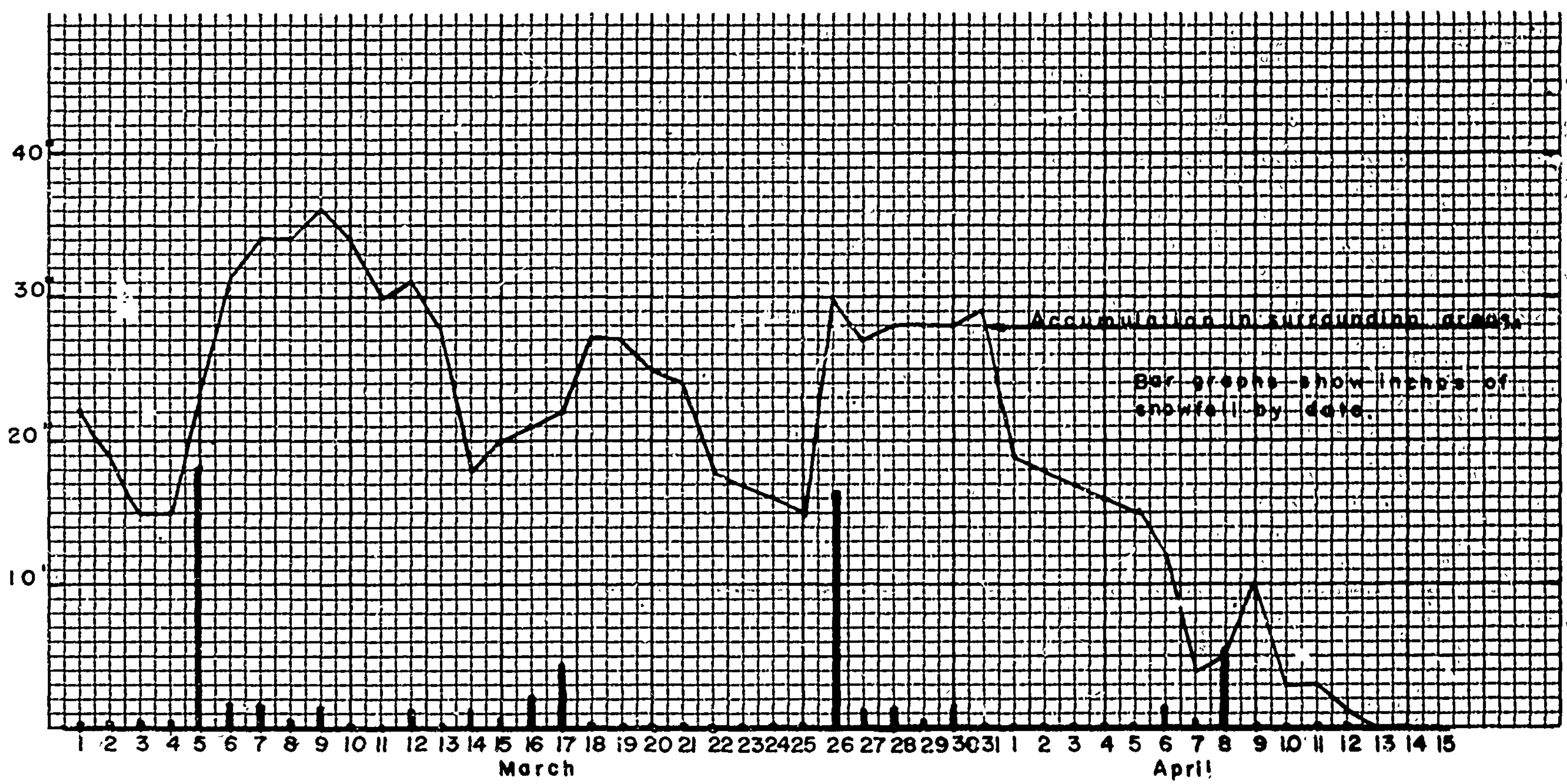


FIGURE 7. DAILY SNOWFALL AND ACCUMULATION RECORD - SAULT STE MARIE, MICHIGAN - MARCH 1 - APRIL 15, 1964

THE TEST INSTALLATION.

The preliminary study of the Kincheloe AFB site indicated the area for 1000 feet forward of the glide slope antenna was level and free from construction. Drawings furnished by the Systems Maintenance Sector Office serving Kincheloe AFB, however, showed an alert ramp taxiway just 520 feet forward of the antennas.

The desired 90° Bp point fell immediately adjacent to this taxiway and could not be used. A point 450 feet forward of the antennas, where Bp was 105°, was chosen for a monitor point.

A 30 foot (above ground level) electric pole was fitted with a track and sliding brackets to hold the test monitor antennas and permit them to be adjusted from the ground. Obstruction lights were provided at the pole top. A weatherproof "detector house" was mounted near the base of the pole to hold the detector and its input hardware.

A type CA-1364 glide path monitor detector was adapted for 50 ohm input and fitted with a coaxial connector for antenna signal input. The input hardware for the detector, consisting of a phaser, adjustable positioning piece, adjustable stub and an M-array glide slope monitor APCU, was bolted to a sub-panel in the detector house. The phaser unit was later removed and phasing was accomplished with the $\pm$ 15° trim-phaser in the APCU. The M-array monitor APCU was a Meridian Model #3211 that combines the input bridge and power divider into a single unit with the trim-phaser referred to above.

The two detector antennas were connected to the APCU through two equal length coaxial cables.

Adjustment of the detector system was accomplished as follows:

1. The antennas were spaced equal distances either side of the path, a total separation of approximately, 1.2°.

2. The antennas were individually connected to the input of a CA-1509 Portable Glide Slope Detector and the antenna heights were refined so that each antenna provided the same ddm indication on the PGSD.

3. The antennas were then connected to corners 1 and 3 of the APCU input bridge.

4. The PCSD was connected to bridge corner (carrier corner) and the antenna line lengths were carefully adjusted for a zero ddm indication.

5. Line length adjustment was double checked by removing the sideband signal at the transmitter and verifying that no R.F. was present at the sideband corner of the input bridge. The transmitter was then restored to normal.

6. The power divider of the APCU was set at half-scale as a starting point.

7. The detector was carefully tuned for a maximum output.

8. The stub and positioning section in the detector input was adjusted for a zero R.F. indication from the sideband corner of the detector bridge(with sideband input disconnected).

9. Steps 7 and 8 were repeated several times to compensate for the interaction between adjustments.

10. The power divider of the APCU was adjusted to provide a convenient level of ddm and the desired sensitivity to path width changes.

The test monitor, a type CA-1363, was modified by adding resistance in one leg of the path calibration potentiometer, R326, so the path channel could be used with the unbalanced input from the test detector.

The clearance channel of the test monitor was paralleled with the clearance channel of the standard monitor. It was necessary to disconnect R386 to secure sufficient signal to operate both monitors from the standard clearance detector.

The dc outputs of the clearance channel and the modified path channel were brought out on shielded leads and connected through isolation and filter networks, to the two channels of a chart type recorder. The isolation networks were necessary to permit normal operation of the alarm circuits. The filtering was required to remove the residual 90 and 150 cycle a.c. component of the d.c. signal.

A Brush Company Model Mark II Recorder was used. This recorder provides two traces, produced electrographically, and an event mark capability for each trace. Each channel has a d.c. amplifier with a choice of balanced or unbalanced input to produce the trace. The event marks are provided by side pens actuated by an internal voltage source controlled by an external switch or push button.

The alarm relay functions of the test monitor were not needed to control any station equipment. It was practical, then, to disconnect one set of relay contacts for each of the two channels and use these relay contacts to operate the event markers of the recorder.

Connected thus, the recorder produced a trace that was related to the ratio of 90/150 cycle audio from each detector, the test detector and the standard monitor detector. It also produced an event mark if either the test monitor or the standard monitor reached an alarm condition.

The channel traces were established in the centers of their respective chart scales so that deviation of the normal audio ratio in either direction would be recorded.

By adjustment of the monitor calibration, and the power divider of the APCU in the detector input, the monitor was made to appear identical in operation to the standard facility monitor.

TEST MONITOR PERFORMANCE.

The test monitor exhibits an improved stability with respect to environment.

It was first noted that personnel moving about in the area between the antenna array and the two detector systems did not affect the test monitor as much as it did the standard monitor. This is evident in Chart Section A, Figure 8. Chart Section B of the same figure is the test dial alarm point check made immediately following A. It may be noted that Section B is made of two pieces. This was done for convenience in presenting the data, to reduce it to a workable size. No constructive data has been lost in the editing process.

The long term stability of the test monitor was at least as good as that of the normal monitor system. A fault in the monitor caused some random shifts of the test monitor recorder cross-pointer. This fault has been definitely isolated to the monitor itself, however, and is not related to the detector system.

The recorder speed used, .4mm/sec., resulted in lengthy recordings, almost 120 feet every 24 hours. Pertinent sections have been cut from these recordings for inclusion in this report.

Figure 9 is a section of recording made just before a snowfall that resulted in a total accumulation of sixteen inches. At the beginning of this period the monitor was reasonably close to being balanced.

Figure 10, Chart Section A, is part of the same recording after considerable snow had fallen. The amount of snow on the ground at that time is not known. It can be seen that the test monitor indication is relatively unchanged but the normal monitor has drifted toward a broad alarm condition. Chart Section B, of this figure, followed Chart Section A by approximately 2 hours. Note that the test monitor has begun to indicate a course broadening, probably due to proximity phase error shift at the test monitor detector site. The standard monitor trace at this point indicates that an alarm is imminent.

Figure 11 chart sections followed those of Figure 10 by less than an hour. These sections show the reaction of the two monitor systems tosnow removal activity in the area around the detectors. The standard monitor alarmed intermittently throughout the snow removal process. (The facility had been removed from service). It can be seen, also, that the test monitor did not approach an alarm until late in the snow removal effort. Observe, at the right edge of Chart Section B, Figure 11, that snow removal efforts had begun to restore the standard detector to its normal indication; that is, the average of the standard detector trace is again near the center of the paper. At the same time the test monitor's trace has not returned to its center chart position. It is probable that snow removal in the larger Fresnel Zone of the test detector had not been completed.

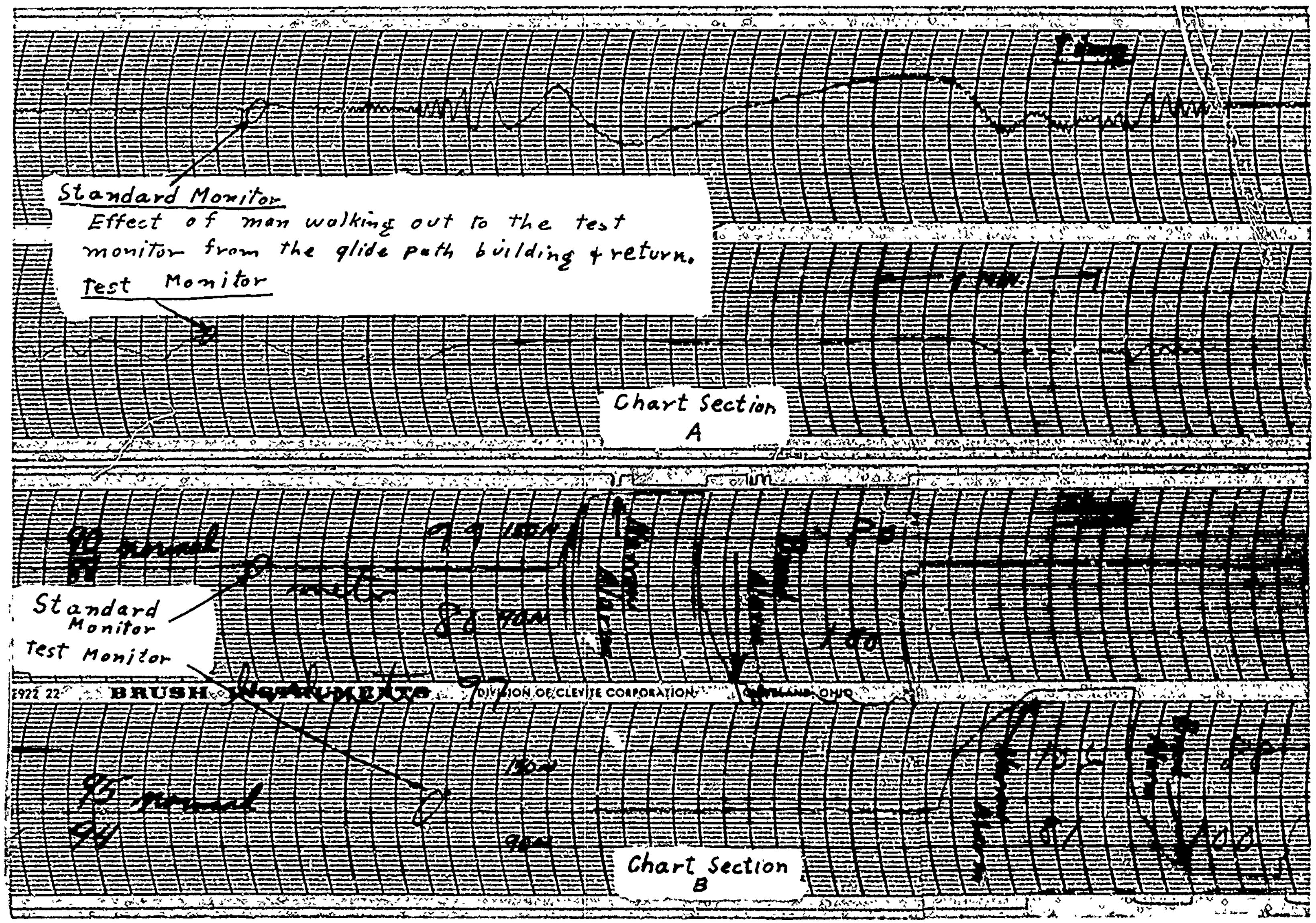
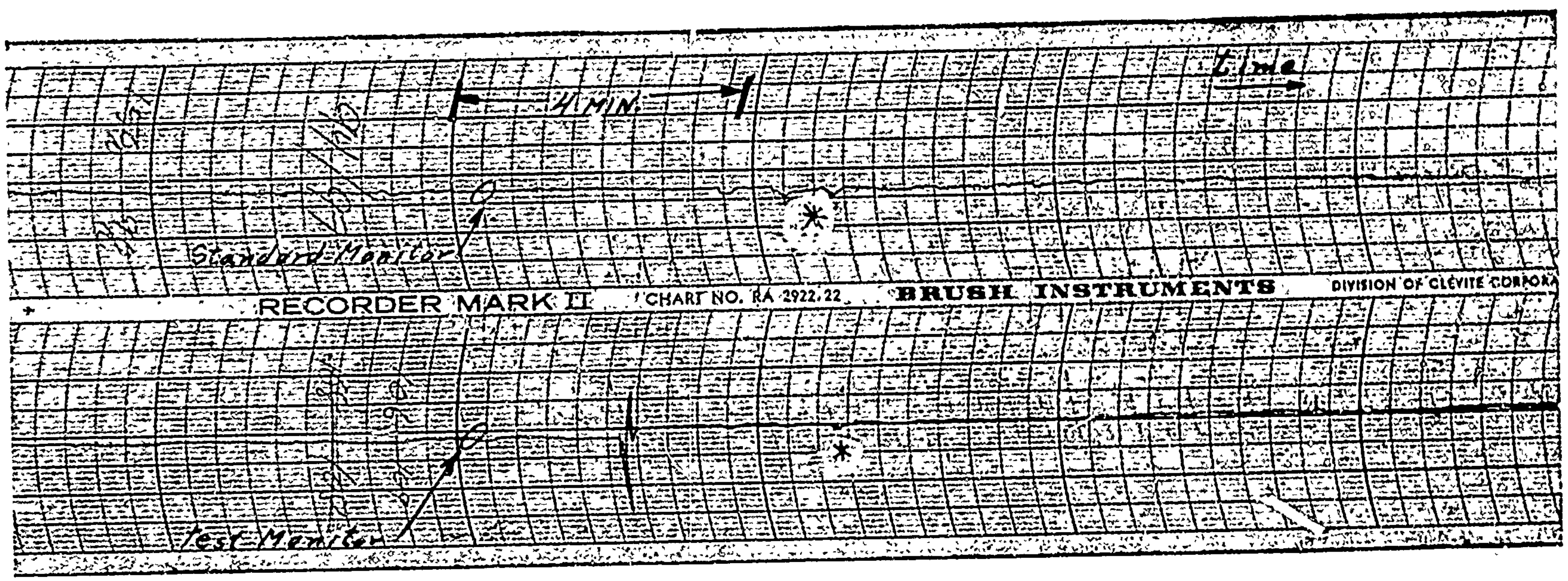


FIGURE 8. CHART SECTIONS - NORMAL OPERATIONS



This chart section, and those of Figures 10 and 11 are taken from a large chart recorded over a twenty-four hour period starting March 25, 1964. The section above was made at the start of this period. The points marked with an asterisk are attributed to the technician departing the site and are typical. The brief excursion on the monitor trace immediately preceding the asterisk is from an unknown cause but probably associated with the technician's efforts to restore the recorded trace to centerline.

FIGURE 9. CHART SECTION - NORMAL OPERATION MARCH 5, 1964

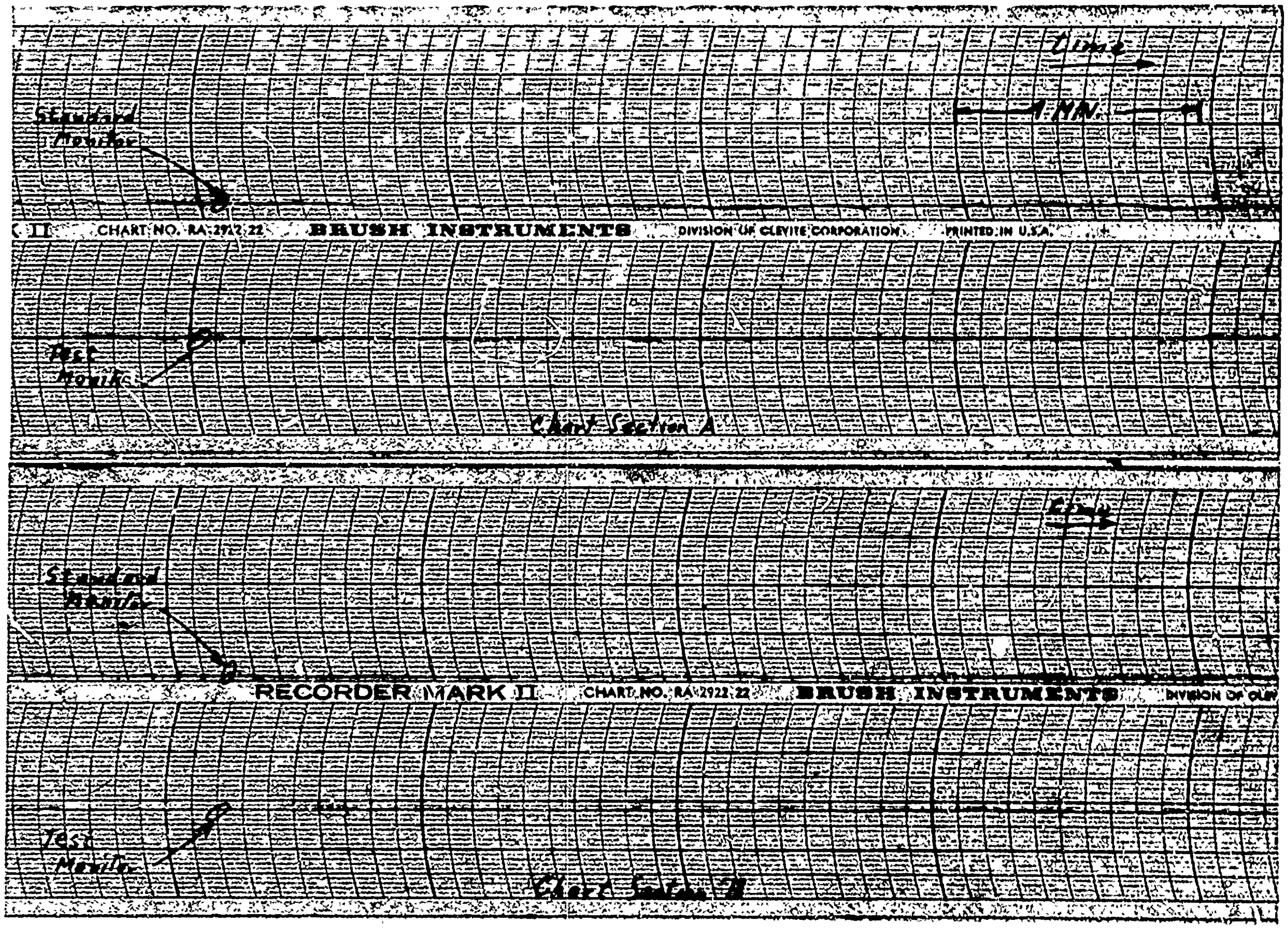


FIGURE 10. MONITOR PERFORMANCE UNDER SNOW COVER CONDITIONS

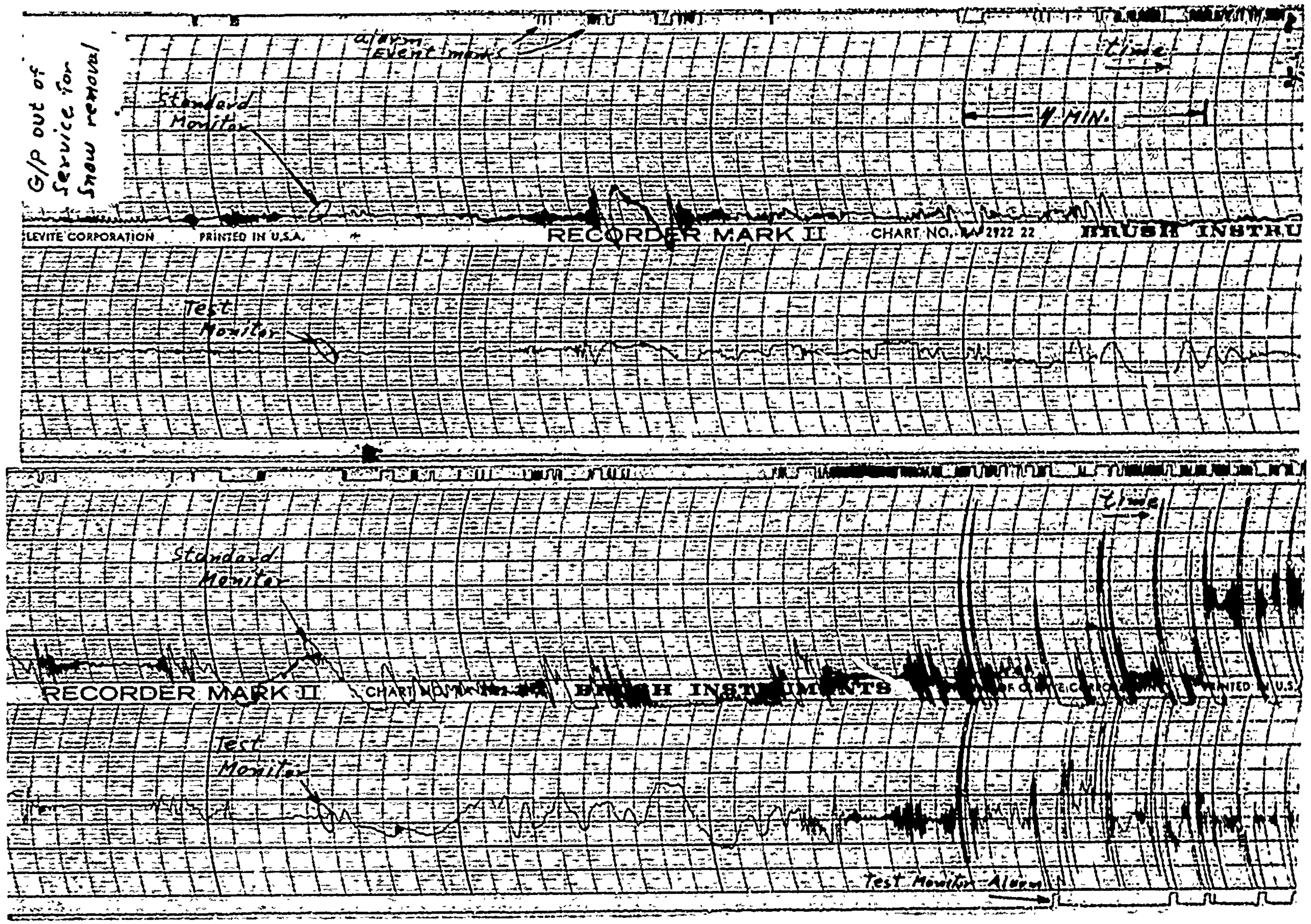


FIGURE 11. MONITOR BEHAVIOR DURING SNOW CLEARING OPERATIONS IN THE MONITOR AREA

CONCLUSIONS

The test monitor system has the following advantages over the present standard ILS glide slope monitor:

1. The monitor responds to the actual path width.
2. The monitor system is relatively free from the effects of snow accumulation in the area between the glide slope transmitting antennas and the monitor detectors.
3. The monitor system is less sensitive to vehicles and personnel working in the near field area.
4. This monitor system may be established using any of the presently available monitors without modification other than to the detector section.

The disadvantages of the test monitor system are:

1. The detector antennas require a mounting mast, of sturdy construction, 30 to 37 feet high. This mast then becomes a considerable air space hazard.
2. The monitor detector requires modification and the addition of R.F. hardware estimated to cost $800.00 - $1,000.00 per site.
3. Additional maintenance is required to maintain the modified detector. The entire input circuit requires readjustment if a detector tube is replaced.

The monitor system would be more attractive if the function of path angle monitoring could be derived from the same antenna system. The savings that would accrue, through elimination of the present monitor rack assembly, would partially offset the cost of establishing this monitor system.

RECOMMENDATIONS

This report recommends that the ILS glide slope monitor problem be studied further before adopting the monitor system evaluated herein.

The reasons for this recommendation are:

1. A mast of the height and strength required for this monitor system is a hazard to landing aircraft.

2. The benefits to be derived from the monitor system are limited unless the path angle monitor can be similarly desensitized to the effects of snow. It is of no benefit to have a happy clearance monitor if the facility is off the air due to path angle monitor alarm.

3. The costs of implementing this monitor system are excessive in view of the limited benefits as outlined in 2, above. An effort should be made to secure a solution that will fit the cost vs benefit concept better.

This report specifically recommends a further study of this particular monitor system to determine if it can be adopted to provide reliable path position monitoring.

If further operational evaluations are to be made, it is recommended that consideration be given to moving the detector pole further from the runway to reduce the obstruction aspects. That is, a line between the glide slope transmitting antennas and the detector antennas would angle away from the ILS runway rather than paralleling it as at present.

APPENDIX

The proposal for the twin antenna monitor system for the ILS glide slope stated that the monitor antennas could be located at any position from 200 feet to 1,000 feet or more from the transmitting antenna. This appendix consists of a study made to support this statement based on a theoretical glide slope having a 2.7° glide angle and a nominal path width of 1.4°. The study indicates that monitor antenna position in the near field may be a critical item and should be near the 90° proximity phase point.

1. Theoretical glide slope parameters:
   path angle = 2.7°
   path width = 1.4°
   H, sideband antenna height = 3820° = 31.2'
   h, carrier antenna height = 1910° = 15.6'
   180° Bp point = 248' from transmitting antenna
   90° Bp point = 496' from transmitting antenna
   λ at frequency of operation = 2.94' (1' = 122.4°)
   Transmitter modulation factor, m =.475
   Elevation of twin detector antennas = 2.3° and 3.1°

2. Development of a ddm formula for the theoretical glide slope:
   path edge, lower = 2.0° (glide angle minus ½ path width)
   path edge, upper = 3.4° (glide angle plus ½ path width)
   ddm at path edge = .175 (by definition)
   ddm = $2m\frac{E_{ss}}{E_{cs}}$ (by definition)
   Solving for E_{ss} at path edge, $E_{ss} = \frac{.175\ E_{cs}}{.95} = .184\ E_{cs}$

   also:

   E_{cs} = Sin h Sin 2.0° (at lower path edge)

   E_{ss} = R Sin H Sin 2.0° where R is the ratio of space sideband audio to carrier audio

   Solving these for E_{cs} and E_{ss} at the lower path edge we get E_{cs} = .918 and E_{ss} = .731R

   Since:

   $E_{ss} = .184\ E_{cs}$ and also .731 R
   We can solve for R: $R = \frac{.169}{.731} = .231$

   Relating these back to the basic ddm formula, ddm = $\frac{2m\ E_{ss}}{E_{cs}}$

   we find that the ddm at any angle, x, is found from the formula
   $$\text{ddm} = .95\left(\frac{.231 \text{ Sin H Sin x}}{\text{Sin h Sin x}}\right)$$

3. Calculation of E_{cs} and E_{ss} at the lower detector antenna:
E_{cs} = Sin 1910 Sin 2.3° = .9724

E_{ss} = .231 Sin 3820 Sin 2.3° = .1044

4. E_{cs} and E_{ss} values at the upper path edge will have the same numerical values as at the bottom path edge. The sign of the E_{ss} value will be negative indicating the phase of E_{ss} at the upper antenna is reversed.

5. Under ideal conditions the sideband corner of the input bridge will yield a total E_{ss} of .209 and an E_{cs} of 0.0.
At the carrier corner of the input bridge, E_{ss} = 0.0 and E_{cs} = 1.95.

6. If these signals are combined in phase, and with equal degrees of attenuation, the resulting ddm = $.95 \frac{.209}{1.95}$ = .102.

7. Using the above formulas and methodology, it is possible to calculate E_{ss} and E_{cs} at the bridge inputs and outputs for various increases in the height of the reflecting plane. In making these calculations, consideration must be given to the effective decrease in carrier and sideband antenna heights and the decrease of the detector antenna heights that are a result of the rising reflecting plane. Graph A is a plot of these changes for the theoretical glide slope when the detector antennas are located at the 180° Bp point.

8. The totals of sideband and carrier signals at the bridge output are of particular interest and these are plotted on Graph B. Note particularly the increase of E_{ss} at the carrier corner of the bridge and the increase of E_{cs} at the sideband corner due to these signals no longer being equal at the upper and lower antenna outputs.

9. Graph C shows the resultant ddm that will be seen after the signals out of the bridge are combined in phase and with equal attenuations. The alarm point reference line is the ddm point that coincides with a 1.8° path width, the limit of tolerance on path width. A correction curve, that must be used to account for a shift in Bp as the reflecting plane rises, is also included.

10. The conclusion that is drawn from these graphs is that the 180° Bp point is not a satisfactory location for the monitor antennas. This is due to the abnormal ddm that is produced by failure of E_{ss} and E_{cs} to be canceled at the carrier and sideband corners of the bridge, respectively.

11. Application of the same techniques to a detector location of Bp = 90° yields an E_{ss}/E_{cs} relationship shown in Graph D.

12. Graph E shows the variation in ddm that results from a rise in ground plane and takes into consideration the effects of the changing Bp. Also shown, is the abnormal ddm that is produced as a result of noncancellation of E_{ss} and E_{cs} at the carrier and sideband corners (respectively) of the input bridge.

13. <u>Graph F shows two ddm curves that</u> may result from the addition of the abnormal ddm to the "normal" ddm. Which curve is obtained in practice is determined by the location of the extra 180° length in the input bridge legs.

14. <u>For convenience in developing this data</u>, we have assumed that the attenuation of carrier and sideband signals from the input bridge to the detector has been equal. In practice, however, the signals from the carrier corner of the input bridge are attenuated by a power divider to permit adjusting the sensitivity of the detector. This attenuation will decrease the abnormal ddm by the same factor that it increases the normal ddm. As an example, a 6 db attenuation by the power divider would double the normal ddm and cut in half the abnormal ddm.

15. <u>The detector antenna location could be so selected</u> that the combined ddm, (normal ddm plus or minus abnormal ddm) would produce a nearly stable ddm indication for variations in ground plane elevation of as much as two feet.

16. <u>The detector location that is used with the monitor system</u> under study will depend on :

   a. The change in ground plane that is anticipated and through which it is necessary to provide width monitoring.

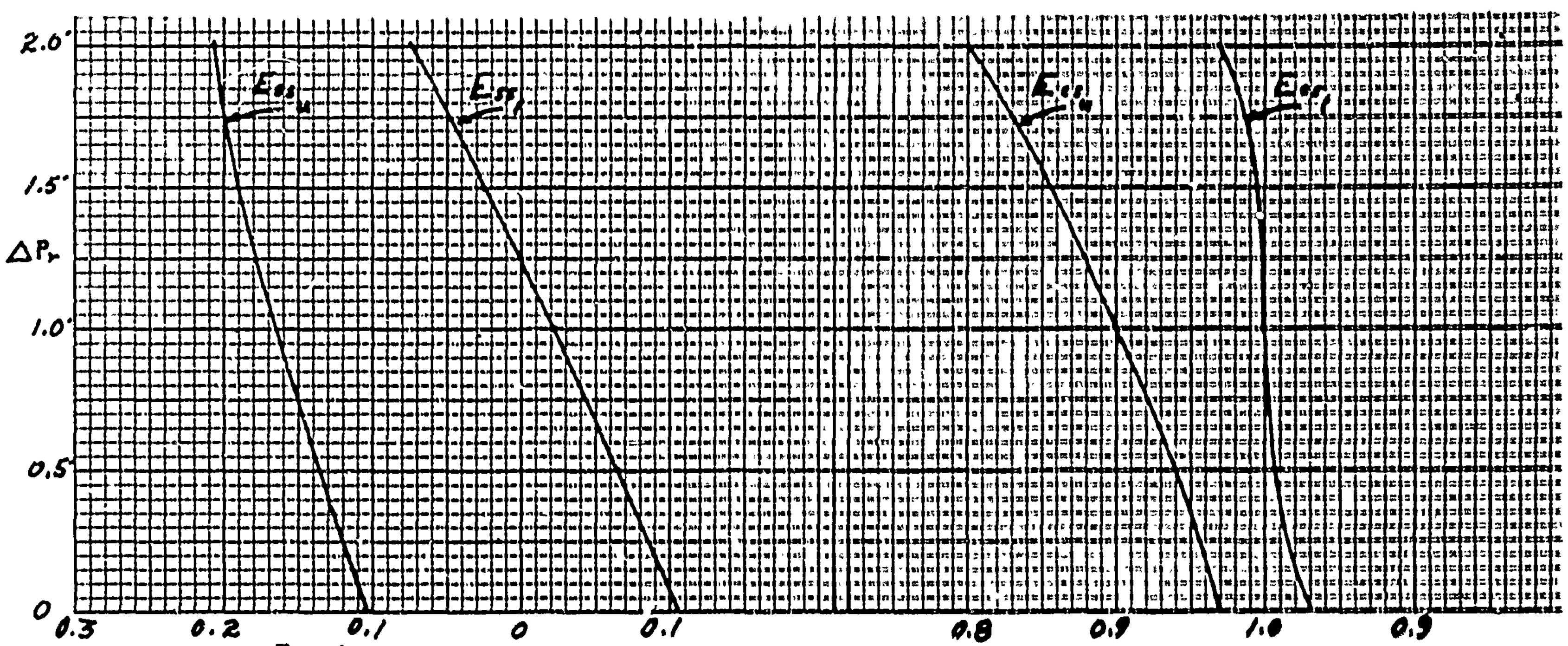
   b. The amount of attenuation that is provided by the power divider.

   c. The lobe structure of the carrier and sideband antenna radiation.

   d. The coefficient of reflection of the ground in the Fresnel Zone.

   e. The separation between monitor antennas (for the effect on E_{SS}/E_{CS} values).

17. <u>Although the detector location to be used appears to be a critical factor</u>, it should be possible in practice to secure quite satisfactory results by varying some of the other parameters, a to e, above.



Graph A E_{ss} (Relative to E_{cs}) E_{cs}

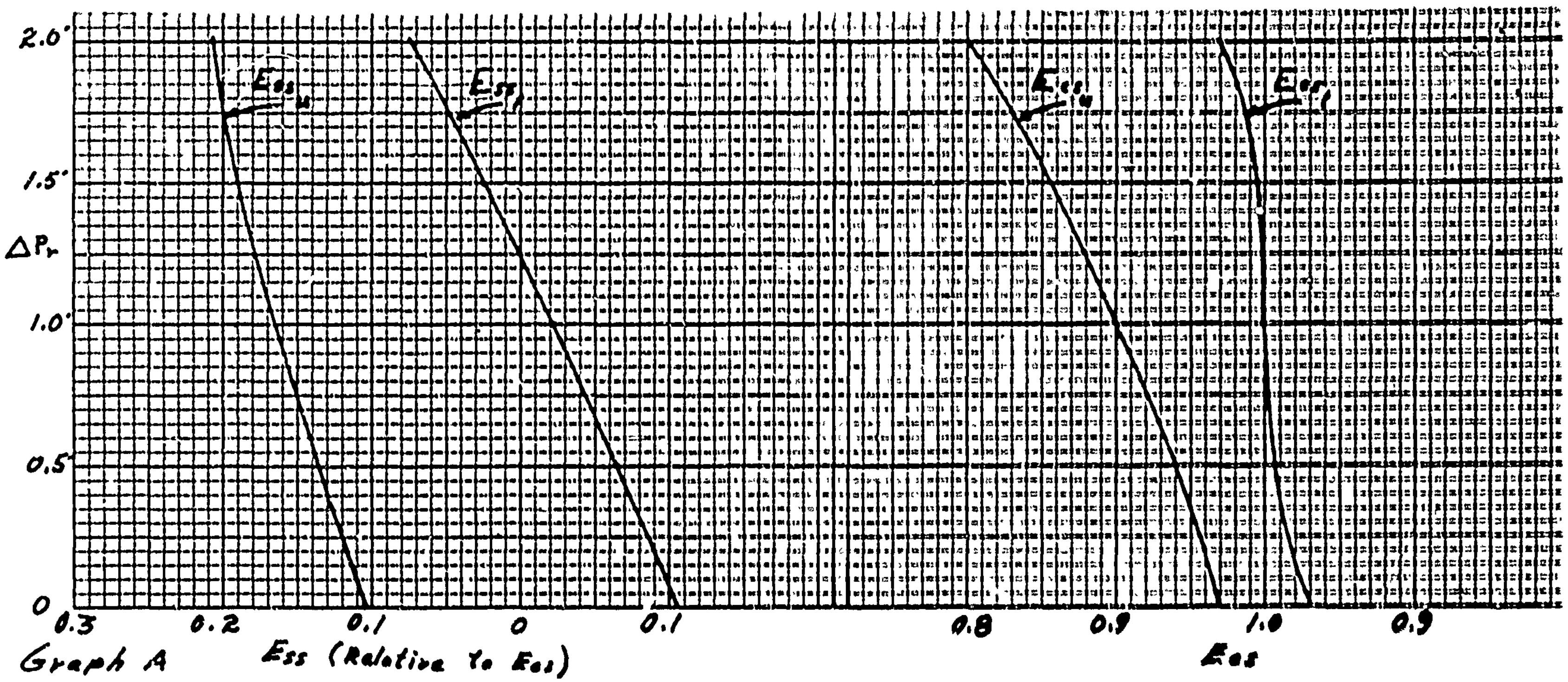
E_{ss_u} is the space sideband signal from the upper antenna.

E_{ss_l} is the space sideband signal from the lower antenna.

E_{cs_u} is the carrier sideband signal from the upper antenna.

E_{cs_l} is the carrier sideband signal from the lower antenna.

ΔP_r is the increase in elevation of the normal reflective plane, in feet.



Graph A

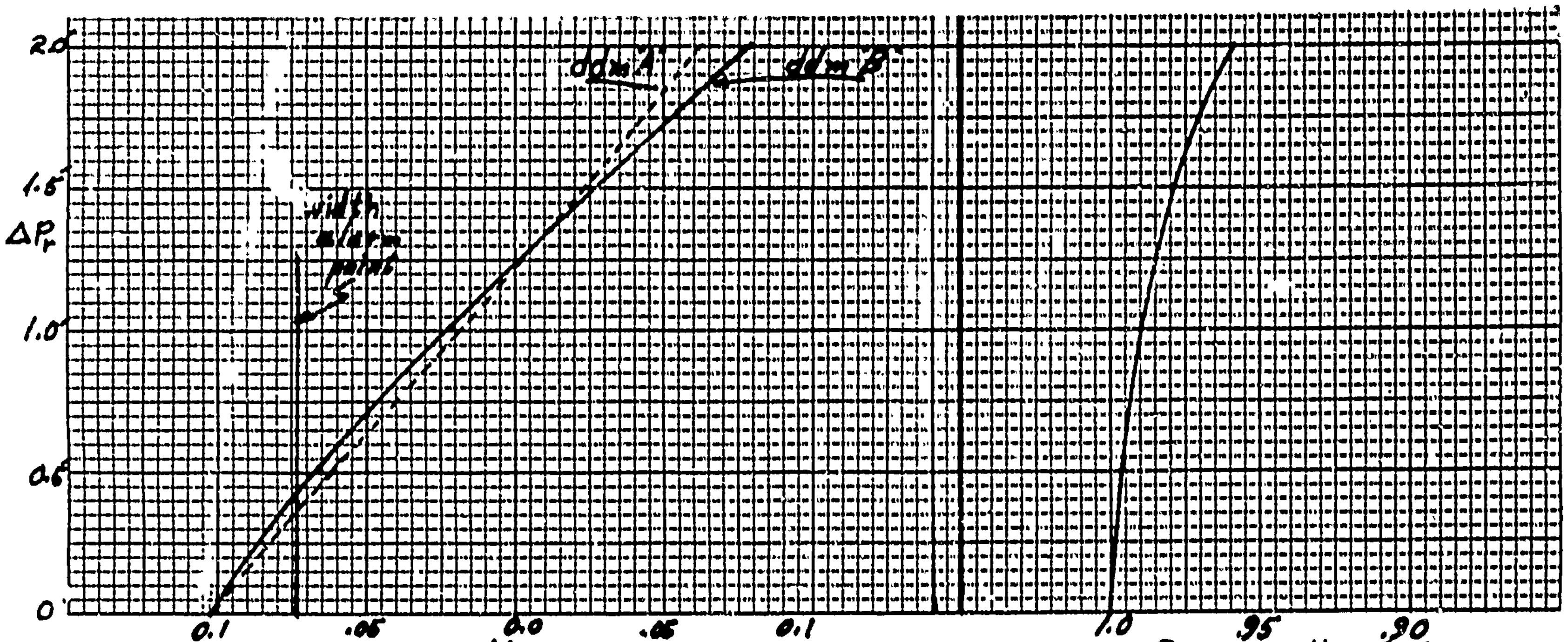
E_{ss_u} is the space sideband signal from the upper antenna.

E_{ss_l} is the space sideband signal from the lower antenna.

E_{cs_u} is the carrier sideband signal from the upper antenna.

E_{cs_l} is the carrier sideband signal from the lower antenna.

ΔP_r is the increase in elevation of the normal reflective plane, in feet.



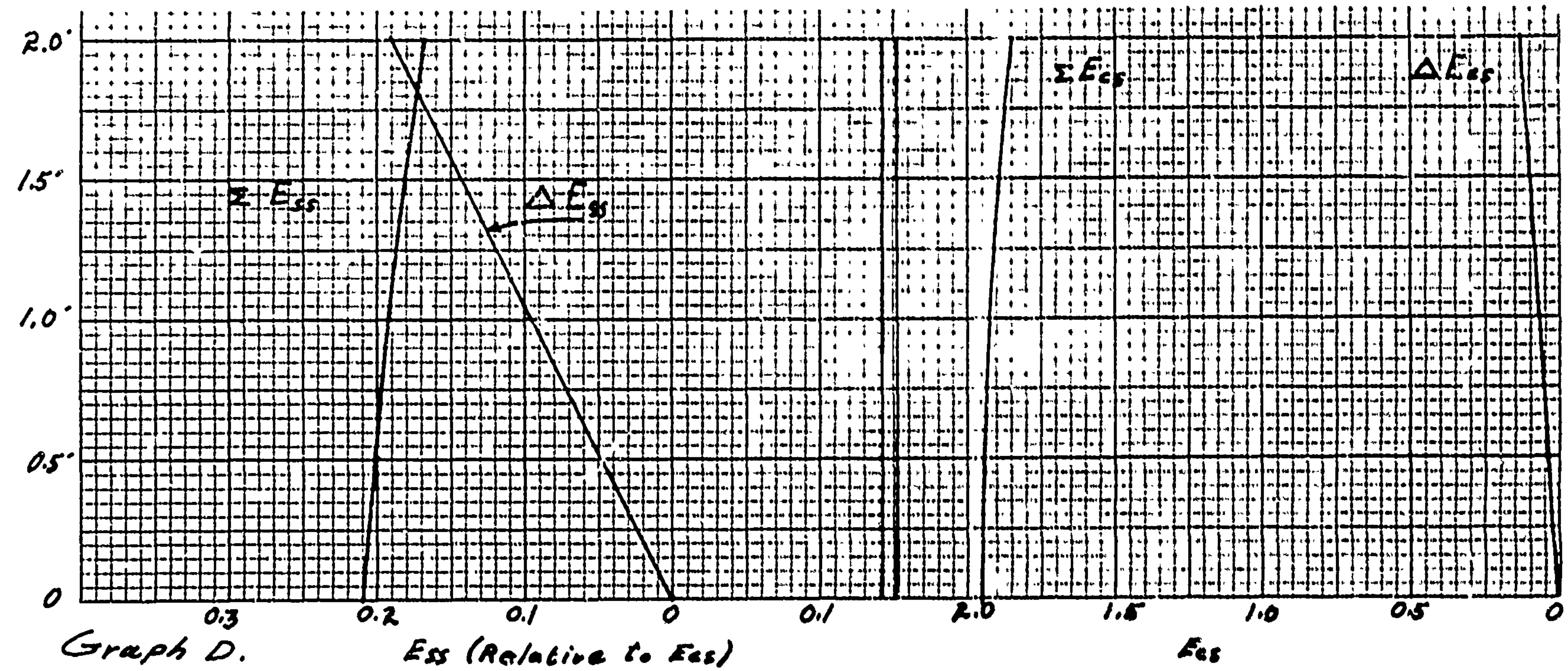
Graph C.

ddm"A" is the ddm (before correcting for proximity error) that results when the longest leg of the input bridge is between the lower antenna and the sideband corner of the bridge. (Refer to sketch on Graph F.).

ddm"B" is the ddm (uncorrected) that results when the longest leg of the input bridge is between the upper antenna and the sideband corner of the bridge.

NOTE: 1. Traces A and B are shown as having the same audio sense (90 cycle versus 150 cycle) for comparison purposes. In practice, reversing the input bridge configuration will reverse the audio sense of the ddm.

2. The graph shows that, for a detector location at $B_p = 180°$, an alarm will occur for a .4 foot change in the elevation of the reflective plane.



Graph D.

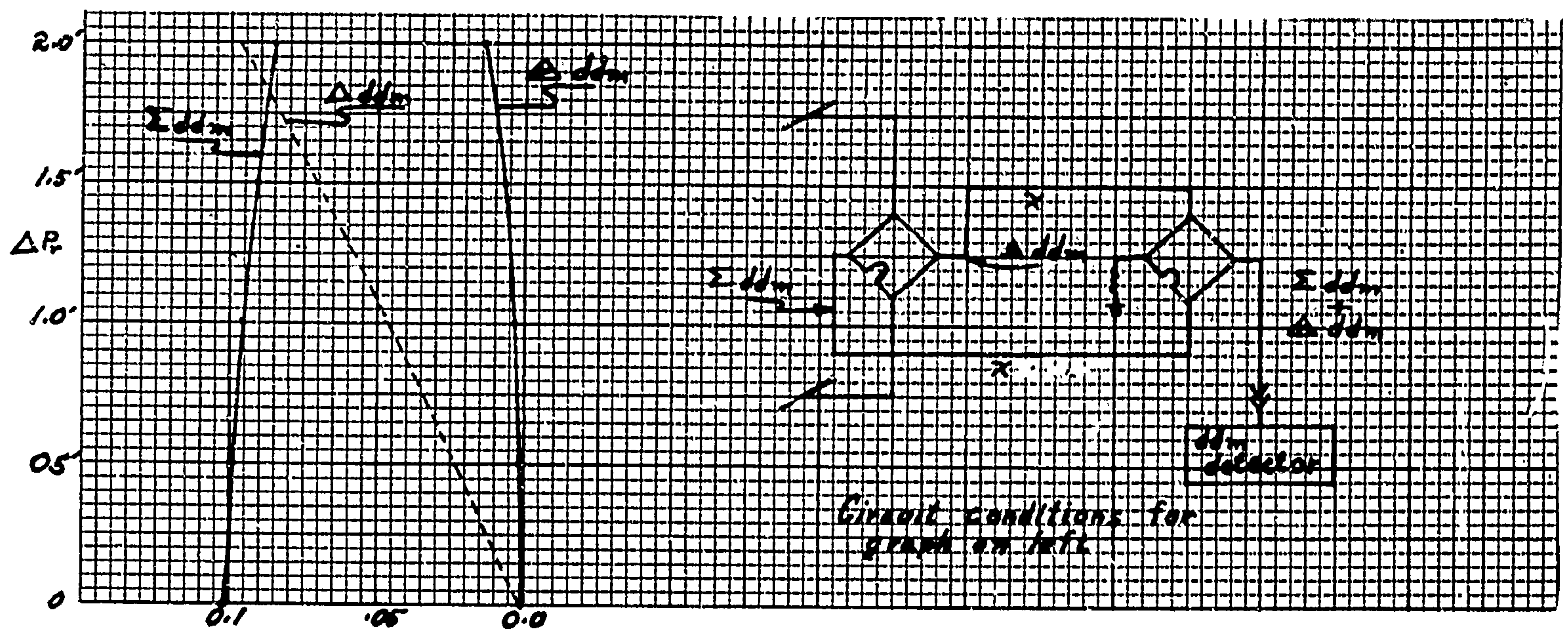
ΣE_{ss} & ΔE_{cs} are the space sideband and carrier sideband signals, respectively, that are present at the sideband corner of the input bridge.

ΣE_{cs} & ΔE_{ss} are the carrier sideband and space sideband signals, respectively, that are present at the carrier corner of the input bridge.

ΔP_r is the increase in elevation of the normal reflective plane, in feet.

Note that the ΔE_{cs} & ΔE_{ss} values are zero under normal reflective plane conditions.

The variation of ΔE_{cs} & ΔE_{ss} are less severe than shown on Graph B because of the greater separation between the transmitting antennas and the detector antennas.



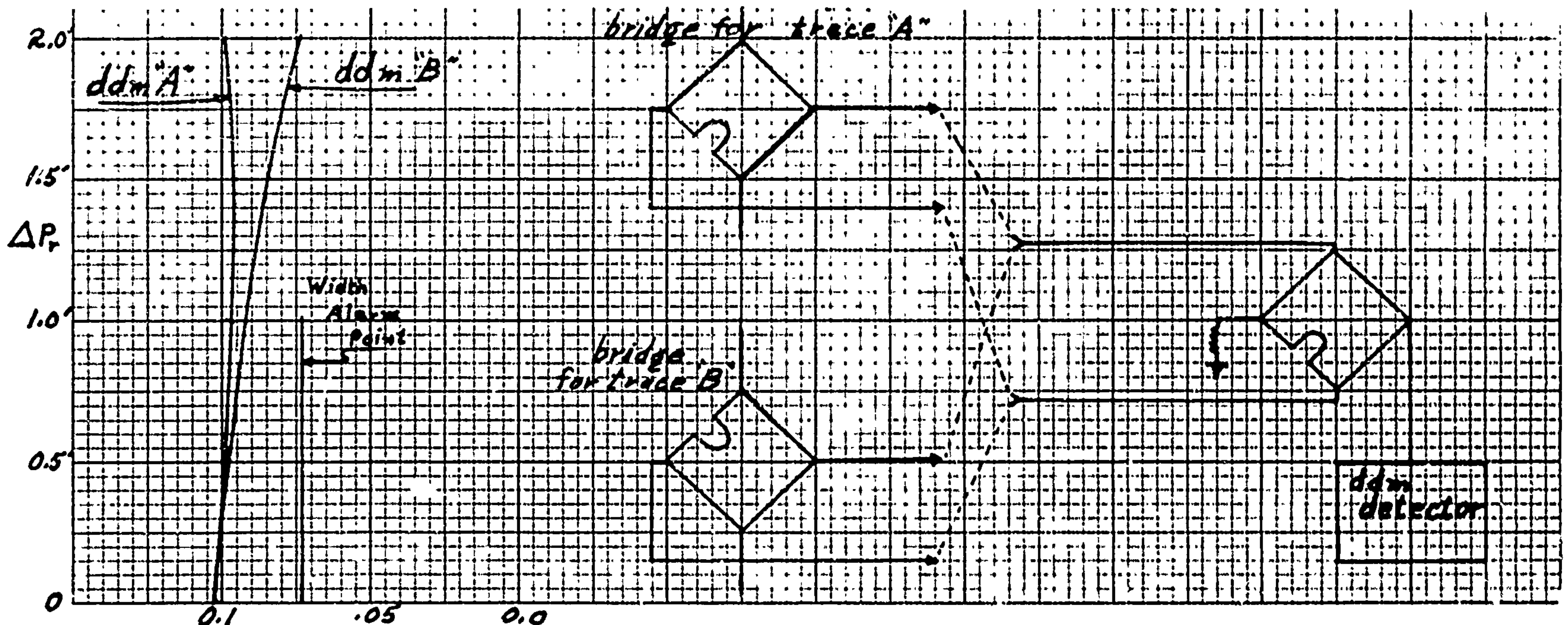
Graph E.

Σ ddm is the ddm obtained by adding E_{ss} from the sideband corner to E_{cs} from the carrier corner in the proper phase.

Δ ddm is the ddm that would result from combining E_{ss} from the carrier corner to E_{cs} at the same corner if they could be phased together.

▲ ddm is the actual ddm that results from combining E_{ss} from the carrier corner to E_{cs} at the same corner when these signals are, under normal reflective plane conditions, at quadrature.

Note on the simplified sketch, that shows the conditions for this measurement, that the sideband and carrier lines are of equal length. If they were other than equal, the Σ ddm may be reduced but the ▲ ddm would not change. The length of these lines influences the audio sense of the ddm indication.



Graph F.

ddm "A" is the total ddm that results when the input bridge configuration of A, in the above sketch, is used.

ddm "B" is the total ddm that would result from the input bridge configuration of B in the sketch.

NOTE:

1. If ddm "A" shows a preponderance of 90 cycle audio, ddm "B" will show a preponderance of 150 cycle audio.
2. A width alarm will not occur in either bridge configuration until the value of ΔP_r reaches at least 2 feet.